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This report proposes an approach to the design of expert system decision aids based on categorizing tactical decision tasks in terms of the limited number of dilemmas inherent in military command and control (C2) operations. Six types of dilemmas are distinguished in the ACADIA typology of tactical decision tasks. These dilemmas are occasioned by the need for the following types of actions as outputs of the C2 cycle: acceptance (of a hypothesis), change (of a course of action in mid-stream), anticipation (of the future tactical interface), designation (of resources to be assigned), implementation (of an action), and adaptation (to a catastrophic event). The ACADIA typology provides a framework for development of generic C2 expert decision aids based on users' cognitive needs. The author discusses some of the operational and training implications of generic expert decision aids based on the ACADIA approach.

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ACADIA: A Cognitive Typology of Tactical Decision Tasks

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FOREWORD

THe MANPRINT Division of the U.S. Army Research Institute for the Behavioral and Social Sciences (ARI) is dedicated to integration of MANPRINT considerations (manpower, personnel, training, human factors engineering, health hazards assessment, and system safety) throughout the materiel development and acquisition process.

One area of concern is the productive application of emerging information technology to aid the battlefield command and control (C2) process. Our lead in information technology, if fully exploited, can provide an effective "force multiplier" that will augment the arsenal of weapons and resources available to our commanders on the battlefield. However, unless carefully managed, the volume of available information may overwhelm rather than help the commander. To reduce the tremendous cognitive burden imposed on combat commanders by the data-rich, highly stressful battlefield, ARI is conducting MANPRINT-oriented research in such areas as information management and display, performance enhancement procedures, and interactive decision aids.

To develop effective interactive decision aids, intensive research is needed to identify the behavioral determinants of effective decision performance. This report describes a typology of tactical decision tasks designed to promote the identification process. The typology is based on a cognitive engineering approach to decision aids that focuses on the internal cognitive processes of the decision maker rather than abstract normative or prescriptive models of decision behavior.

ACADIA: A COGNITIVE TYPOLOGY OF TACTICAL DECISION TASKS

EXECUTIVE SUMMARY

Requirement:

Expert system technology is viewed as a promising means to help reduce the tremendous cognitive burden imposed on combat commanders in the data-rich, highly stressful battlefield environment. Our lead in information processing technology, if fully exploited, can provide an effective "force multiplier" that will augment the arsenal of weapons and resources available to our armed forces. However, current and projected military requirements, even for the next few decades, far outstrip the capabilities of current decision-aiding (particularly expert system) technology. To meet future needs, an architecture for decision-aiding systems suited to the unique requirements of tactical command and control operations must be developed.

Procedure:

To escape the limitations of the current highly task-specific approach to computerized decision aids, generic systems capable of handling broad classes of decision tasks must be developed. An approach to developing such generic systems is described here. The distinguishing feature of this approach is that it groups together decision tasks that differ markedly in terms of their external, objective features but that can be grouped together in terms of common cognitive characteristics.

Findings:

A typology of tactical decision tasks has been formulated by the author based on dilemmas faced by commanders on the battlefield. Six types of dilemmas are distinguished in what is labeled the ACADIA typology of tactical decision tasks. These are the following: acceptance (of a hypothesis), change (of a course of action in midstream), anticipation (of the future tactical interface), designation (of resources to be assigned), implementation (of a course of action), and adaptation (to a catastrophic event).

Utilization of Findings:

The ACADIA typology provides a framework for development of generic decision-aiding systems based on users' cognitive needs. The benefits of generic systems include increased commonality of equipment designs, software architectures, and operational procedures. These benefits will influence both operations and training. Because the ACADIA approach can be implemented in manual as well as automated systems, continuity of command and control readiness can be maintained during technological insertion.

ACADIA: A COGNITIVE TYPOLOGY OF TACTICAL DECISION TASKS

CONTENTS

LIST OF TABLES

Page

LIST OF FIGURES

ACADIA: A COGNITIVE TYPOLOGY OF TACTICAL DECISION TASKS

SECTION I

INTRODUCTION

Background

Need for a New Approach

Expert system technology is widely viewed as a promising means for providing decision aids to people faced with complex problem solving and decision making tasks (Rouse, Geddes, & Hammer, 1990). An area of particular concern to military planners is the need for decision aids to help reduce the tremendous cognitive burden imposed on combat commanders in coping with the data-rich, highly stressful battlefield environment. Our current lead in information technology, if fully exploited, can provide an effective "force multiplier" to augment the arsenal of weapons and resources available to commanders of combat units. However, current and projected military requirements, even for the next few decades, far outstrip the existing primitive expert system technology (Walker, 1987).

In order to meet future requirements, intensive research is needed to develop architectures for intelligent interfaces that are suited to the unique requirements of military applications. For example, decision aids in the battlefield environment must operate in real time. The conventional view (Crowder, 1986) is that this requirement drives the need for

> "a new hardware architecture, which provides by several orders of magnitude, increased computing power, faster execution speeds and larger storage capacity" (p. 65)

The position taken here, however, is that the real need is for an architecture that focuses on the internal cognitive requirements of the decision maker rather than the hardware or other external characteristics of the decision situation: in other words, a framework based on a cognitive engineering approach (Woods and Roth, 1988; Rasmussen, 1987) rather than a hardware engineering approach.

This report describes a typology of tactical decision tasks (ACADIA) that is suggested as a basis for such a framework. This taxonomy was developed to provide an alternative approach to the development of expert system, intelligent interface and other computerized aids to support the command and control (C2) process. The six categories of the ACADIA typology (Acceptance, Change, Anticipation, Designation, Implementation, and Adaptation) provide a context in which information gathering and display parameters are defined by the user's needs rather than by the domain-specific features of the task. The ACADIA approach

can be used in the design of generic expert consultation systems to assist or coach a decision maker in an operational environment. It is equally applicable to the design of training systems designed to impart knowledge or to test the skill level attained or sustained by C2 personnel.

The characteristics of the C2 process and the current approach to the design of decision aids to support this process are discussed in the remainder of this section. In Section II, the characteristics of each of the ACADIA decision tasks are detailed along with examples of some of the considerations important in their effective resolution. Decision makers often exhibit deficiences or lapses in the cognitive domain in the course of responding to complex decision tasks. In Section III, some examples of such behavioral traits that could be monitored using expert system technology are discussed. The identification of such traits and the criteria by which they can be assessed are important in 1) teaching individuals to be more effective decision makers and 2) evaluating the performance of decision makers during tactical training exercises, e.g., command post exercises, war games, and simulations. Section IV contains a discussion of some applications of the ACADIA typology with respect to operational decision support systems, technological insertion, and training.

Expert Systems

An expert system is a type of computerized system designed to aid humans in decision making, problem solving, diagnosis and other judgmental tasks. It does this by manipulating a knowledge base in accordance with certain procedural rules. The expert knowledge contained in the system is composed of factual information, procedural rules for manipulating this information, metarules (i.e., rules for applying the procedural rules), and heuristics (i.e., rules of thumb based on plausible reasoning, good guesses, etc.). These are encoded so as to be accessible to a logic module in the computer, the so-called inference engine, which operates on the knowledge base to draw appropriate, logical conclusions.

In addition to their reasoning ability, expert systems (also known as "knowledge-based" systems) can perform many of the secondary functions usually provided by human experts. For example, Hayes-Roth (1985) has noted that expert systems can be designed so that:

- They interact with humans in appropriate ways, including the use of natural language.
- They manipulate and reason about symbolic descriptions.
- They function with erroneous data and uncertain judgment rules.
- They contemplate multiple competing hypotheses simultaneously.

- They explain why they are asking a question.
- They justify their conclusions.

The design of a knowledge-based expert system is thus an attempt to capture the knowledge and expertise of subject matter experts, to transfer these to a computer program, and to make them readily accessible to other persons. The objective is to create an "advisor" or "coach" for users faced with problem solving or decision making tasks in a specific knowledge area. To attain this objective a new technology has been developed comprised of an amalgam of artificial intelligence, computer theory and design, cognitive science, human factors and other technologies.

In principle, knowledge-based expert systems can be designed for any situation where there exist the facts and heuristics used by subject matter experts for solving problems or making decisions. As a result, the techology has witnessed explosive growth in recent years. Literally thousands of reports have appeared in the scientific and technical literature within the past decade dealing with various aspects of expert system theory, design and application. These recent advances, particularly in artificial intelligence (AI) and computer theory and practice have stimulated a considerable amount of Department of Defense (DoD) supported research and development (R&D) in this area. A search of the Defense Technical Information Center (DTIC) data base using "expert systems" as key words yields over 500 titles. These include reports on expert systems designed for applications such as logistics (Allen, 1986; Jakowski, 1987); maintenance (Laffey, Perkins, & Firshein; 1984: Antonelli, 1984); image interpretation (Rueda, 1986; Bashkar, 1985); and, of particular concern here, command and control (Teter, 1986; Albano & Gearhart, 1988; Blanchet, 1987).

A significant portion of the R&D currently underway is in the application of expert system technology to the development of military decision support. These efforts, while in many cases highly innovative and productive, have had little impact upon military technology. This has been due in large measure to the fact that expert systems developed to date have been restricted to highly specific knowledge domains or problem areas. They are "task specific" to an extreme degree. Very little of the resultant technology or software can be utilized by persons not intimately associated with the specific area of concern. This ad hoc approach has produced fascinating glimpses of the potential of expert system technology. By and large, however, the research has had little impact outside the agency sponsoring the work and almost none upon system acquisition and military planning specialists.

What appears to be lacking is a framework or architectual schema within which to develop generic decision support systems, i.e., systems useable in more than a single or limited number of application areas. It should be a framework within which systems can grow and evolve in concert with the technological growth that

can be expected in the future. Most importantly, it should be a schema that is focused on the cognitive aspects of the decision making domain, rather than on the mathematical or algorithmic analysis of various tangible, external features incident to the decision environment. The purpose of this paper is to describe a "cognitive" typology of decision tasks that is suggested as a framework within which generic C2 expert system decision aids can be developed.

The application of interest here is not the development of automated systems intended to serve as surrogate decision makers. Rather, it is the incorporation of current and evolving expert system technology into the data management and the data display processes used in command and control (C2) information systems. The primary goal is to devise a "cognitive" architectural schema within which decision aids for tactical decision making can be designed.

Expert Systems in Command and Control

Tactical Decision Making Defined

A tactical decision is defined here as an action taken by a commander, who by definition has been given authority, to apply the military force at his disposal at the time and place and in the quantity of his choice. These actions are taken to fulfill the responsibility (concommitant with the authority) vested in a commander to provide directives to his subordinates. These directives provide his subordinates with the go-ahead to carry out the operations needed to defeat or thwart an enemy force on the battlefield.

Tactical decision making is thus an exercise of judgment within constraints. The commander's choice is constrained by:

- The policy and strategy of higher authority;
- The environment in which he is to operate;
- His knowledge of the enemy forces;
- The state of his own and other friendly forces.

In its simplest form, tactical decision making involves merely the initiation of a suitable course of action, e.g., sending a sufficient counterforce (10 interceptors) to meet a given threat (5 attackers). The design of decision aids for tactical commanders would be a relatively straightforward matter if it involved nothing more than an instruction to apply the predetermined course of action that would effectively resolve the tactical problem. Unfortunately, rarely if ever does the real world situation take the form of the simplest case. In practice, the commitment to a particular course of action and the timing of that action are contingent upon a large number of other factors or parameters associated with combat operations.

In the case of an armored defensive operation, for example,

these include such diverse factors as (1) the destructive capacity of the attackers e.g., their number and weapon capabilities; (2) the absolute and relative priorities of areas or objects to be protected; (3) the proximity of the attackers (to each other, to friendly forces, to areas of differing priority); (4) the absolute and relative rates of movement of friendly and enemy units, (5) the completeness and reliability of the information regarding the attackers (which may or may not increase with time); (6) the need to retain reserve forces or capabilities to meet unexpected changes in the situation; etc. These and many other factors can render a seemingly simple task, i.e., "rule following", into one of overburdening complexity.

Tactical decisions are distinguished here from other types of decisions associated with combat operations. Decisions are constantly required of military personnel in the analysis of battlefield data produced by external sensors, to solve supply or transport problems, to maintain personnel and equipment in a state of readiness and other problem solving situations. Such decisions constitute informational inputs to the C2 process. They are not, however, tactical decision making i.e., the process manifest in the command directives issued to the unit in fulfillment of the responsibilities vested in the commander.

For example, consider the situation in which intelligence data provides numerous indications that the enemy is getting ready to launch an attack. Upon thorough analysis, the G2 might conclude that the enemy will launch an attack at some specific location and time. This is an important conclusion but it is not a tactical decision. Rather, it is an informational input for a tactical decision. Until the commander directs the unit to take some action to counter this assumed enemy action, a tactical decision has not been made.

The Command and Control (C2) Cycle

Tactical decisions occur as part of the C2 process. The C2 process is a continuous cycle that involves repeated iterations of a number of sub-processes that occur in five interrelated and usually sequential phases (see Figure 1). These five phases are:

a) Information Gathering
b) Assessment
c) Planning
d) Decision
e) Execution

For purposes of exposition, the C2 process will be discussed in terms of the interaction of a commander and his staff. This is indeed the case at the higher echelons. At battalion, for example, one or more individuals are assigned to one of the five staff functions, viz., S1 (Personnel); S2 (Intelligence); S3 (Operations); S4 (Logistics) and S5 (Civil Affairs). At division level, dozens of officers and enlisted personnel are members of

the general staff. At and below company level, however, the C2 process is localized largely within the commander himself, although various individuals may supply some of the informational inputs. At the lowest level, e.g., a tank platoon leader, the process is internalized entirely.

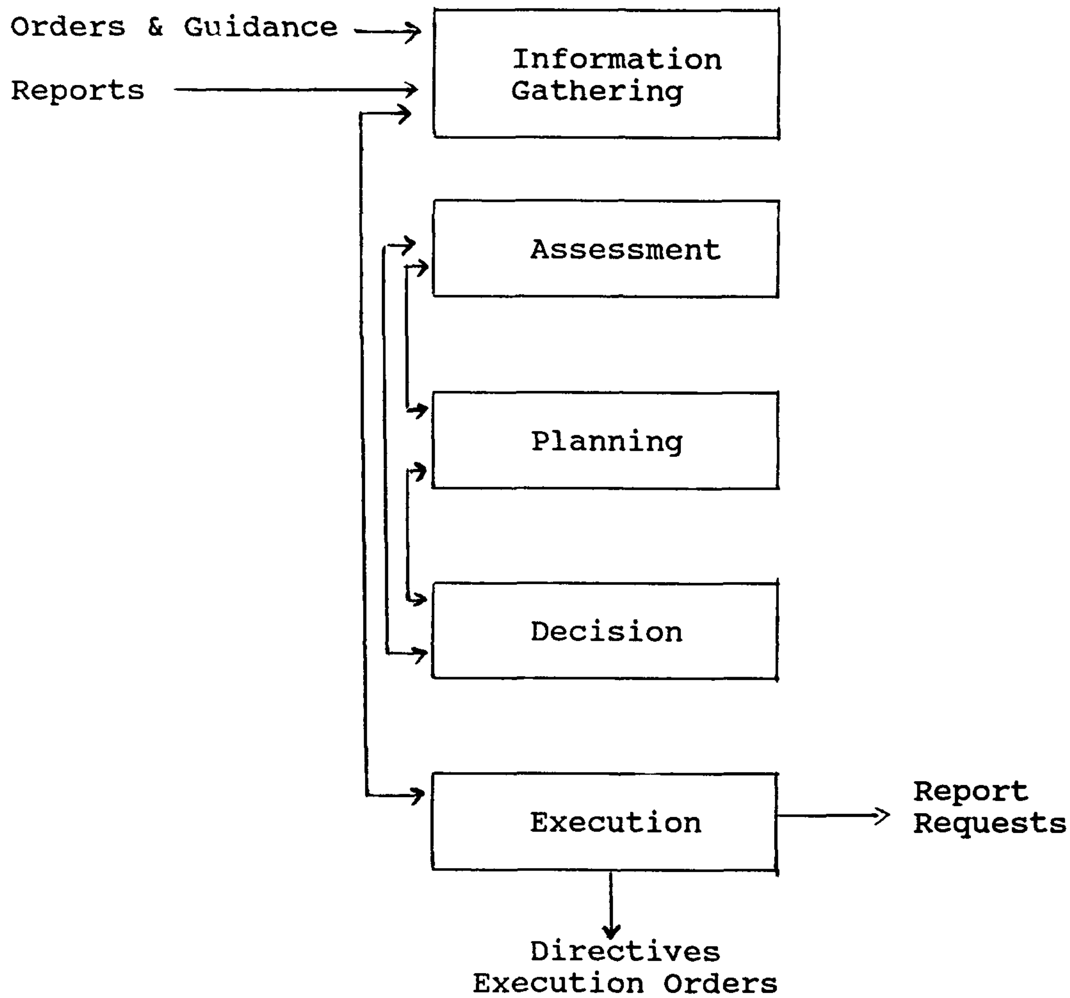

Figure 1. The Command and Control (C2) Cycle.

However, even when internalized within an individual commander these five phases of the C2 process are useful as a descriptive model of the nature and sequence of the cognitive processing involved in tactical decision making. This reinforces the contention that the most productive approach to the design of C2 expert systems would be the development of generic decision aids; more specifically, development of knowledge-based expert systems and intelligent interfaces that employ the same principles of data management and display regardless of echelon, functional branch, or branch of service.

The following are brief descriptions of the purposes and activities associated with the five phases of the C2 cycle.

Information Gathering The process of information gathering covers the provision, gathering, storage, consolidation and validation of data that will be used during the subsequent phases. During this phase staff officers assigned various functions continuously interact in order to maintain information on the status of friendly forces (operations), enemy forces and actions (intelligence), logistics, personnel and other aspect of the tactical situation. Because of the volume of information involved the display and presentation of such status information usually requires the application of filter functions in order to help the staff concentrate on significant issues and to avoid unnecessary detail.

Planning In the planning phase, assessments derived during the previous phase are used to form the basis for various potential courses of action. Many planning tasks will have been completed prior to the commander's decision being made. The consequences of executing each potential course of actions needs to be analyzed and evaluated. After the comparison of available courses of action, the staff prepares a recommended one for the commander's consideration. The planning phase at higher levels of command (e.g., Corps, Army) may involve in-depth analyses requiring days to complete. At lower echelons (e.g., brigade, company), the time available may be only hours or even minutes. Reassessment or replanning is sometimes necessary after the commander's review of the staff's proposals.

Assessment The assessment phase consists of analysis, evaluation, comparison, and review of the data provided in the first phase on the basis of directions obtained from superior headquarters and in light of the commander's concept of operation. The assessment phase may be initiated by specific important events or by routinely scheduled commander's briefings. The assessment tools and criteria used differ considerably depending on echelon and the functions performed by various staff elements. The commander is usually involved in this phase and may provide direction to his staff for the following phase.

Decision In the decision phase, the commander is briefed on his staff's considerations. Various courses of action will be proposed and one recommended. The decisons taken may cause the implementation of plans produced during the previous phase or may result in direct mission changes or requests to higher or lateral headquarters for additional information or support. Decisions will frequently cause reassessment or replanning as well as the completion of tasks initiated during the previous execution phase. During the decision phase an intensive dialogue between the commander and his staff takes place. The staff is therefore required to review the results of previous phases very quickly.

Execution The execution phase implements decisions, effects

formal interactions with other commands, and covers tasks normally considered to be within the purview of senior staff decisions or direction. Actions during this phase may cause reassessments or replanning. During the execution phase many subordinate decisions that follow from the commander's decision need to be taken and coordinated. In addition, all activities which have been initiated will be monitored and may lead either to corrective direction within the execution phase or to reassessment and replanning in the following C2 cycle.

The C2 cycle shown in Figure 1 applies at all echelon levels, but different levels may well be operating in different phases at the same time. For example, the execution phase at one level initiates assessment and planning phases at the lower levels. The lower the level, the greater the need for detail and the more severe the time constraints. At the lowest level, it may be necessary to accomplish the cycle within minutes while at the highest levels iterations of the cycle may occur over a period of hours or days.

The decision phase is supported by all other C2 phases and therefore improved performance in any phase of the cycle should result in improved and more timely decisions. In addition, time saved through automation will free the commander and his staff from many of the routine functions. This would enable the commander to devote more of his time and energy to other command functions, such as leadership, which cannot be automated.

The Command Briefing

The primary source of C2 information for a commander at brigade or higher level is the headquarters briefing. This formal military procedure consists of a series of presentations by staff members who normally prepare view-graphs, maps, and other graphics and visual aids covering their specialist subject. Based on available information regarding the disposition and condition of friendly and enemy forces, the operations staff estimates the options available to the commander who makes the final choice, i.e., makes the tactical decision. The operations and planning staffs then prepare necessary directives and orders.

This formalized briefing process has several weak points. First and foremost, too much raw detail is accumulated which requires a great deal of time to analyze and aggregate before the implications become apparent. In effect, there is a long lag between the acquisition of data or information and its assimilation. Consequently, assessments and judgment may become out of phase with events. Too much reliance must be placed on verbal communication (e.g., voice, telephone, radio) which consumes valuable resources, is open to misinterpretation and is notoriously inefficient.

Transfer of information by this briefing process is often not very efficient. At Corps level, for example, the commander

himself has the task of integrating a dozen or more specialist briefs to form the total, dynamic picture. Specialist information is often presented in the form of a complicated matrix. Explanations by word of mouth are slow and open to misinterpretation. Maps, diagrams, charts, and other graphics which can provide a superior portrayal of the changing environment are difficult to create and update.

Other Expert System Applications

It is necessary to consider the above noted general features of the C2 cycle and the command briefing in the development of expert C2 decision aids. The potential value of expert system and intelligent interface technologies lies not only in their contribution to the decision process per se. They can also contribute to more effective operation of the entire C2 infrastructure with respect to data analysis, planning and information management and distribution. At present the C2 process is a very labor intensive, mostly manual operation. Because of this there is a constant danger of the intrusion of various discrepancies or anamolies in its efficient operation, e.g.,

- Guidance, constraints, and policy may be lost when transmitted to lower and adjacent echelons.
- Distributed data bases and numerous sources of essential C2 information may make data gathering difficult and time consuming.
- Accurate data management is difficult: commanders and staff must frequently use information that is out of date; resource status reporting is fragmented; there is a heavy committment in personnel and time to "bean counting " and "bookkeeping."
- The lack of systematic planning tools for resource allocation to maximize tactical capabilities (force mix, logistics, terrain exploitation, timing) can result in inefficient use of resources and loss of flexibility.

The above factors must be considered in the development of an appropriate architecture for military decision support systems. An expert system developed in isolation will inevitably fail because such changes must be kept current to be acceptable to current users. Also, the C2 system must be continuously maintained to preserve battlefield readiness.

Because of the environment within which the C2 process occurs is only partially structured, and because of the enormous complexity of the process, it is at present impractical to apply a fixed set of rules and algorithms as the basis for direct automated decision support for commanders. As a result, the command and control process remains essentially an exercise of judgment within constraints. Expert system technology appears to be a medium for utilizing automated, computerized processes to aid this exercise of judgment.

Weaknesses of the Conventional Approach

Expert system technology does show promise. But as the technology moves out of its infancy, it is showing signs growing pains. Problems exist in both of the new technical specialties which form the core of expert system technology, viz., knowledge engineering and representational models.

The process of acquiring the knowledge and heuristics (rules of thumb) used by subject matter experts, known as knowledge engineering, is very complex and time consuming. Buchanan and Shirtliffe (1984) note that the current state of the art in expert systems is characterized by:

- Narrow domains of expertise. Because of the difficulty in building and maintaining a large knowledge base, the typical domain of expertise is narrow.
- Limited knowledge representation languages for facts and relations.
- Relatively inflexible and stylized input-output languages.
- Laborious construction.

Other deficiencies observed by Gervarter (1985) have produced similar problems. He notes that the form of the expert system design is governed by characteristics of the stylized input-output languages of the machine rather than the language of the user. Also, the structure as well as the content of each knowledge base is the unique result of the singular interaction of the knowledge engineer and the subject matter expert.

Significant problems also exist in the domain of software design. Although the knowledge base is a critical factor in building an expert system, the power of the system depends largely on choices made by the software specialist with regard to the forms of representation and reasoning. Some of the methods currently used include propositional and predicate calculus (Nilsson, 1981); semantic networks (Winograd, 1982); production systems (Winston, 1984); semantic primitives (Shank and Abelson, 1977), and frames and scripts (Winston, 1984). In many, if not most cases, choices of methods for representing uncertainty and other attributes of the knowledge base have been ad hoc (cf Cohen, Thompson, and Chinnis; 1985). As a result, they lack normative justification, and may in fact lead to counterintuitive results in some applications (Buchanan and Shirtliffe, 1984).

Cohen et al. (op. cit.) point out that

> "the focus on modeling experts in this tradition has had another consequence: relatively little attention has been given to expert system users. Artificial intelligence contributions to the human-computer interface have, for the most part focused

on input-output issues (e.g., spatial data management, natural language understanding, voice data entry), rather than the design of knowledge representations and inference mechanisms that conform to user requirements. Work in expert systems on explanation and mixed-initiative dialogues has emphasized an essentially passive role of users, as initiators of queries, recepients of answers, and providers of raw, undigested data." (p. 7)

It thus appears that work in expert systems, while highly innovative and productive, has been somewhat disjointed. There appears to be little architectual commonality based either on on process or subject matter. Instead, expert system design may be considered to be an art form, like custom home architecture.

Thus, the question of how to represent knowledge in the data base remains a critical issue in the development of expert systems. At present, the particular application largely determines the selection of the knowledge representation schema and the architecture that will support that representation. Since there are currently no models of human decision making applicable to more than certain well circumscribed domains, this selection must be made very carefully and often somewhat arbitrarily. For this reason, the first thing that is done in designing an expert system is to analyze the task domain well enough to select what is judged to be the best structural formalism for representing the knowledge that will reside in the system's knowledge base (Hamill, 1984). It is this decision that drives subsequent decisions about the appropriate system architecture and the nature of the inference engine that will search the knowledge base in the course of problem solving and decision making applications. This analysis is invariably based on a compilation of the objective, observable facts related to the physical components or actions involved in executing the task. In short, the system is designed in terms of the objectively defined task.

But the notion of "designing for the task" is ultimately a logical trap in view of the innumerable tasks performed by people today, let alone those the future will bring. Furthermore, ad hoc solutions to specific problems, no matter how ingenious, are not likely to coalesce spontaneously into a broad, coherent technological base. Without such a base, it is unlikely that expert systems technology will have much of an impact on the theory and practice of military command and control.

The problem of "designing for the task" will remain intractable so long as the conventional wisdom (Feigenbaum, 1980) holds that it is the contents of the knowledge base rather than the control structure (rule integrator or "inference engine") that gives an expert system its power. This view has lead to a preoccupation with constructing data bases whose components (facts, rules, and their relationships are based on attributes of the external world that are derived from properties

of the physical or mathematical models used to represent the task. As a result, proving the model rather than aiding the human becomes the actual goal. Decision performance produced by various mathematical (e.g., Bayesian) models, while often not very good, is invariably better than that produced by humans alone. Since these mathematical models have provided us with our successes to date, we have become bemused with developing decision support systems that use the human to improve the performance of the model.

Despite the many short term successes to date, in the long run the process of devising expert systems "designed for the task" will lead to a blind alley if the tasks continue to be defined strictly within the context of mathematical models. For one thing, users typically (correctly?) perceive these models as artificial and something painfully, reluctantly, and incompletely learned. Moreover, even if the model meets its design goals successfully, it provides only information, not a tactical decision. Something else must be added to our conceptual arsenal if we wish to escape the "one task: one expert system" trap. To achieve relevance to specific tasks and generalizability across tasks, a cognitive language must be developed to escape the language of particular tasks, as well as the language of particular computational mechanisms, and to identify "pragmatic reasoning situations" (Woods and Roth, 1988).

SECTION II

A NEW APPROACH

As noted earlier, the application of expert systems technology appears to provide a means for unburdening the heavy cognitive load imposed by the complexities and stress of combat. But a task-by-task, system-by-system development of expert systems is impractical. In the long run a more effective approach would be to devise an approach based on generic systems capable of handling broad classes of decision tasks. A new approach to the development of such generic systems will be described here. The distinguishing feature of this approach is that it groups together tasks that are deemed to be functionally similar in the cognitive domain despite apparent differences in their "objective" features and the environmental contexts in which they occur.

This typology is built on the notion that the essence of tactical decision making is the resolution of conflicts between the needs and the capabilities of the tactical unit. A battlefield need that can be met within the normal pre-established operational capabilities of the tactical unit does not progress beyond the information gathering phase of the C2 cycle. Its occurrence may be noted but no command action is taken. But when an assessment is made that the cost-to-benefit ratio of the tradeoffs available to the tactical unit in meeting a battlefield need approaches 1:1, the commander has the responsibility to break the impasse, i.e., to resolve the dilemma.

ACADIA: A Cognitive Typology of Tactical Decision Tasks

Six types of dilemmas or decision tasks are distinguished in what is labeled the ACADIA typology of tactical decision tasks. These dilemmas are occasioned by the need for the following types of actions to occur as outputs of the C2 cycle:

- Acceptance (of a hypothesis).
- Change (of a course of action in midstream).
- Anticipation (of the future tactical interface).
- Designation (of resources to be assigned).
- Implementation (of an action).
- Adaptation (to a catastrophic event).

In the ACADIA typology, tactical decision making is considered to be an aspect of the responsibilities imposed upon a commander to aid his tactical unit to accomplish its combat mission. A tactical unit is comprised of any assemblage of military personnel and equipment organized to provide an effective means for performing a previously established operational (combat) function. A tactical unit may thus be a fighter aircraft, a tank platoon, an infantry division, a guided missile frigate, or any unit established to employ force to eliminate or reduce the capability of the opposing force (OPFOR) to fight.

The ACADIA typology is suggested as a starting point for devising a framework or architecture for generic C2 expert systems. Each of the dilemmas provides a distinct context within which the decision task is organized. Although the specific battlefield environments in which the decisions must be made may differ in many significant details, the structure of the data base, the representational schema, the type and format of the information input and output will be the same or very similar for all situations that require the resolution of the same type of dilemma.

The ACADIA typology focuses on the users' perception of the decision task. This makes it more likely that the structure and operation of an expert system decision aid will be compatible with the user's frame of reference, i.e., have a high degree of "cognitive compatibility." Because the structure and operation of the expert systems designed within this conceptual framework would be largely independent of the external task characteristics, their applicability would be more-or-less universal. A basically similar system would be used by battlefield commanders regardless of the echelon, combat arm, or branch of service.

The six dilemmas that comprise the ACADIA typology can be briefly characterized as follows:

Acceptance Type Decision Tasks

A frequent occurrence on the battlefield is the acquisition of some significant but limited amount of information regarding the OPFOR; for example, data regarding the OPFOR's possible presence, location, or direction of movement. If these data indicate that some attribute or characteristic of the OPFOR has exceeded a threshold, the tactical unit must assume the operational stance that will enable it to best cope with this event. That is, the various elements within the tactical unit must interact in a coordinated way to implement a pre-established set of operations in response to this new status of the OPFOR.

Responses made in fulfilling the responsibilities imposed by this type of situational requirement constitute one of the major types of tactical decision tasks. That is, the response by which a decision maker indicates to the rest of the tactical unit his "acceptance" of a hypothesis that a set of data (e.g., thermal returns) represent some object (enemy tank) or, particularly with processed data, some tactically significant attribute of the OPFOR; e.g., OPFOR Brigade X has launched an attack at location Y.

Many responses that can be classified under the Acceptance category are based on an analysis of the physical or other "objective" characteristics of the OFFOR. These include responses made in carrying out such functions as detection, identification, localization, and damage assessment. However, many others are based on characteristics attributed to the OPFOR that are the products of cognitive operations carried out by the individual. For example, assumptions regarding the enemy's intentions or goals

require an Acceptance decision. These include aspects of the OPFOR such as its likely route, its scheme of maneuver, its tactical objective (town, hilltop, bridge), its tactical "mode" (attacking, reconnoitering) and other attributes that are not inherent in the observable signals but are attributed to the OPFOR by the decision maker.

Examples of Acceptance type decision tasks are manifest when a commander issues directives to the tactical unit to take action because he is convinced that the OPFOR is:

- massing for an attack
- breaking through at point X
- attacking now, (will at time x)
- focusing his attention on location Y
- changing tactics
- changing objectives

The information about the OPFOR is almost always ambiguous because the actual status of the OPFOR is not directly or completely observable. The information that is available is usually fragmentary, redundant, and of less than perfect reliability, e.g., spot reports of sightings of small OPFOR elements or signals produced by remote electronic sensors. Furthermore, the OPFOR is trying to disguise its true status as much as possible; by misleading maneuvers, false volume and type of electronic signatures, or other means. Therefore, some individual within the tactical unit is required to transform the available but ambiguous or incomplete data into a form that provides meaningful information; meaningful in the sense that it serves as a signal for the initiation of a pre-established set of responses by various individuals within the tactical unit.

Although many different kinds of hypothesis demanding tasks exist, involving many different kinds of situations, sizes and types of units, or information domains; they all are basically Acceptance dilemmas. Therefore, they can be handled by a generic expert system architecture. Obviously, not all of the many factors involved in these different situations are of equal importance or relevance. But the general approach to the knowledge engineering process, to the data base organization and management, to the soldier-machine interface are similar, if not identical.

The two horns of the dilemma in an Acceptance type decision task are: 1) making a false positive error and thus responding prematurely, or 2) making a false negative error and responding too late. A response made too early can result in such undesirable consequences as:

- wasted resources and assets
- alerting the OPFOR of own units presence, status, intentions, etc.
- confusion of adjacent friendly units
- starting a hard-to-stop process

A response made too late can result in such negative consequences as:

- higher casualties to own or other friendly units
- loss of position, terrain,etc.
- loss of tactical momentum
- loss of resources or assets
- inability to forestall OPFOR
- failure to accomplish mission goals

A premature Acceptance response, even if correct can cause problems because it may mislead the decision maker by giving him the impression, based on a limited sample, that he is "bold" or "clever." Similarly, a delayed response that proves to be "correct", e.g., the OPFOR did not launch an attack despite many compelling indications, may mislead the decision maker by reinforcing an unwarranted notion that he is "cool" and level headed under pressure.

Examples of the types of data and heuristics that would enter into the expert system knowledge base associated with the resolution of an Acceptance dilemma are shown in Table 1. These are examples of cognitive factors that transcend the domain specific characteristics of battlefield environments that differ widely in many specific details. Such domain independent factors provide an appropriate context for the elicitation of knowledge and heuristics in the development of cognitively homeomorphic knowledge bases for C2 decision aids.

Table 1. Considerations in Resolving an Acceptance Type Dilemma

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- consequences of premature response
    - loss of resources
    - alert OPFOR to own capabilities, location, etc.
    - confuse friendly units
    - loss of tactical position
- ability to recover from premature response
- diversion of attention, resources
- cost of waiting if X is indeed true
- probability of OPFOR feint
- utility of responding to feint
- reversibility of response
- time available before it is necessary to respond

One of the actions that a commander might take in attempting to resolve the dilemma is to seek more information. An expert system could assist by specifing or estimating various factors associated with the action, for example,

- time available for information acquisition
- cost of acquiring information in terms of

personnel, equipment, or other resources
- time needed to acquire info vs time available
- likelihood of getting more and or better information
- sources:
  - of direct information
  - of indirect information, i.e., corroboration

To be effective, an expert system must provide means for the decision maker to indicate characteristics or actions attributed to the OPFOR. This has important implications for the design of the data management architecture as well as the display format and other aspects of the soldier-machine interface.

Change Type Decision Tasks

Another recurrent command dilemma arises in situations in which the decision maker is faced with a choice between continuing a present course of action (or modus operandi) or initiating a new and presumably more effective one. The decision tasks put in this Change category are those dealing with the question of whether or not to make a major change in the overall operational mode of the tactical unit while still trying to accomplish a previously established tactical objective. The decisions associated with minor adjustments made in the course of the inevitable fine tuning of the tactical unit's activities are not included nor are the decisions made in situations requiring a sudden and complete abandonment of the tactical unit's mission. The latter are discussed below under the Adaptation category.

Situations calling for the serious consideration of a change type decision are usually a by-product of the Assessment phase of the C2 cycle. They typically occur when a large body of positive or negative information has accumulated which prompts a re-assessment of the current tactical course of action. The antecedents for such a Change type decision may be: 1) a positive event (unexpected lack of resistance); 2) a negative event (unexpected high resistance); 3) a stalemate; or 4) the needs of an adjacent friendly unit.

The dilemma encountered in such a Change type decision task is a serious one since the new course of action will significantly restructure the tactical interface between own unit and the OPFOR; for example, the question of whether or not to break radio silence upon encountering an unexpected large enemy force. Because of the dynamic character of the battlefield, the commander is usually under a great deal of pressure. If the decision is not made in a timely manner, the opportunity to make the change may be lost.

Examples of situations that give rise to such Change dilemmas are encountered in all walks of life, e.g.,

- Warfare: Change attack objective from "A" to "B"

- Industry: Change major product line from full sized autos to compacts.

- Football: Change game plan from a ground game to a passing game.

The dilemma arises because invariably the proposed new course of action has associated with it real or potential losses which tend to counterbalance the expected gain(s). Since the decision response alters the fundamental nature of the interface between the tactical unit and the OPFOR, its consequences will be far-reaching. Many of these consequences are predictable and their impact can be evaluated. However, a danger always exists that various unintended and undesired consequences may also result, particularly since the analysis leading to a Change decision will usually not be as complete or systematic as the original decision. Also, less time is typically available to the commander.

Examples of the type of data and heuristics in the knowledge base associated with the resolution of a Change type decision task are shown in Table 2.

Table 2. Considerations in Resolving a Change Type Dilemma

- probability of success of new versus present course of action
- relative benefit to be obtained by new course of action versus loss resulting from abandonment of present course of action
- impact of the change on logistics, transport, air cover, artillery support or other support functions.
- adequacy of the information regarding the new course of action
- likelihood of more or better information
- coordination required
    - degree to be expected
    - cost in resources, time, loss of momentum, etc.
- impact of the change on higher and lower echelons, adjacent or other friendly units
- validity and reliability of the information indicating a need for a change
    - possibility of OPFOR deception
    - invalid information regarding gain or loss
- value of present gains to be lost versus value of gains expected by the change

Another, and perhaps more serious, consideration is that the change may not conform to the expectations or the capabilities of others. These others may be personnel within the tactical unit as well as commanders of units adjacent to or in echelons above or below that of the decision maker. Thus, an important

consideration is the added burden of communicating with all of the individuals and units that may be affected by the change in some tactically significant way. An example of such an effect was provided by GEN (ret) B. C. Clark (Clark, 1986) in recounting the circumstances that led up to the WWII Battle of the Bulge. GEN Clark noted that:

> "The rapid advance of Patton's Third Army - from the breakout at the Avranches beachhead ... to the Moselle River and Nancy - took 40 days instead of the planned-for 70 days. At that time the Third Army was out of gasoline and was held up for six weeks, which gave Hitler time to prepare the Ardennes counteroffensive." (p. 20).

A consequence was a "battle that cost our Army 78,000 casualties over a seven-week period."(op. cit., p. 21).

Anticipation Type Decision Tasks

Another type of dilemma frequently encountered in warfare is occasioned by the need to establish the optimum interface between own tactical unit and the OPFOR at some future point in time. This occurs when it is not feasible for the tactical unit to immediately resolve the tactical situation. The inability to resolve the situation may be because: 1) the OPFOR is too far away; 2) the tactical unit is not fully prepared; 3) it is necessary to first coordinate with other tactical units; 4) it is necessary to wait for certain events to occur first; 5) the information regarding the OPFOR is too diffuse or fragmentary to act upon, etc. Thus the decision maker is faced with the task of preparing for an anticipated event. He must issue directives that will put the tactical unit in a specific operational stance at some future point in time.

Like Acceptance decision tasks, Anticipation tasks involve interpreting and transforming data generated by the OPFOR. However, a new variable - time - must be considered. Furthermore, in addition to extrapolations based on the physical attributes (speed, direction, etc.) of the OPFOR, this decision task will usually require a judgment regarding the OPFOR's intentions.

The essential dilemma of an Anticipation decision task is whether to respond in a bold or a conservative manner. If the commander correctly surmises the OPFOR's capabilities and intentions, he is in a position to maximize the effectiveness of of his own resources. By properly disposing his own forces, i.e., "getting there fastest with the mostest," he will be able to counter the enemy while expending a minimum of resources and suffering a minimum of casualties. If he acts boldly (as if 100% confident that he has predicted the OPFOR's future disposition) and responds accordingly, he will obtain the maximum gain with a minimum of loss - if he is correct! However, if his bold response

is 100% wrong the opposite will most likely occur - minimum gain and maximum loss. On the other hand, if he makes an extremely conservative response and is wrong, he runs the risk of such negative consequences as: 1) relinquishing valuable terrain; 2) being out of position (e.g., outflanked); 3) allowing the OPFOR to gain momentum; 4) loss of initative or maneuverability.

To resolve the dilemma, the commander must make a judicious compromise. He must position his unit in such a way that he can counter any of the feasible maneuvers or actions by the enemy while giving up the minimum of his assets, e.g., terrain, resources, tactical capability, maneuverability, or momentum.

The adequate resolution of this type of dilemma does not require the decision maker to anticipate every detail of the OPFOR plan of action or specify with absolute certainty the exact future location (or other attributes) of the OPFOR. Rather, the adequacy of the decision is the extent to which the course of action that it implies is a reasonable way to cope with the situation. Thus, it must take into account, among other things, the lack of certainty as to the OPFOR's actual intentions, future location, or future status. In the usual situation it is not possible to ascertain the enemy's intention in great detail. Furthermore, the OPFOR may change its actions or objectives as a result of the actions taken by the decision maker. Therefore, the commander must consider and respond to a broad range of possible OPFOR actions.

For example, a commander might conclude that the OPFOR was about to begin a drive to seize rail junction X. His internal dialogue might go something like this:

1) "If I am 100% certain that X is the OPFOR's objective, the best chance to forestall them is to position the tactical unit at location Y and perform action Z."

2) "If I am only 50% certain that X is the objective, the best response is to go to location Y' and perform action Z'."

3) "If I assume that the objective is X (50% likelihood) or X' (50% likelihood), the best response is to go to location Y'' and perform action Z''."

In the general case then, an Anticipation decision task requires a commander to assume the responsibility for structuring the tactical interface between his tactical unit and the OPFOR at some future point in time based on currently observable and inferred attributes of the OPFOR.

Outputs of Anticipation type decision tasks include:

- OPFOR will be at location X at time T; therefore, the tactical unit must be at location X' prior to time T.

- OPFOR will be in X condition (start advancing) at time T; therefore, the tactical unit must be in condition Y (defense formation) prior to time T.

- OPFOR will perform action X when situation Y exists; therefore, the tactical unit will perform action X' when situation Y exists.

Example of some of the types of data and heuristics in the knowledge base associated with the resolution of an Anticipation type dilemma are shown in Table 3.

Table 3. Considerations in Resolving an Anticipation Dilemma

- Maneuverabilitly of own unit and OPFOR
  - absolute and relative
- Priority of areas or resources to be protected, e.g., even if it reduces resources or options, certain areas must be protected
- Benefit vs risk trade-offs in moving to a location close-in to anticipated OPFOR future location
- Benefit vs risk in holding back to retain maneuver options
- Availability of reserves or ability to recoup, e.g., even if the initial OPFOR thrust succeeds, they may be countered later
- Degree of required external coordination with adjacent and other friendly units including:
  - cost of effecting required coordination.
  - feasibility of effecting required coordination
- Maneuver security, i.e., avoidance of traps or exposure of flanks
- Available supply of assets and resources (N.B. even if assets are wasted, own unit can gain valuable information or other advantages)
- Overextention of resources, options or other assets

Designation Type Decision Tasks

Decisions of the Designation type reflect the requirement for the selection of one alternative from a set of alternatives. Tactical units are specifically organized to deal with certain events or situations that are expected to occur in the course of military engagements. They are provided with various resources and assets to enable them to cope with the expected contingencies. However, there remains the need for someone to exercise the responsibility to select (designate) the particular resource or action available to the tactical unit that is best suited to a particular time, place, or circumstance. The ultimate responsibility for making the selection or designation resides in the commander.

Designation type decision tasks are usually a by-product of the Planning phase of the C2 cycle wherein the staff analyzes the options available within various categories of resources available to the tactical unit. These include such tasks as assigning the unit to lead an attack, allocating artillery support or air cover to various units, and selecting locations for setting up a strong point. They then recommend the particular option within each category that will best support the overall course of action recommended to the commander.

The dilemma in this situation results from the fact in many situations no one option is clearly superior to all the others or free from some sort of disadvantage or cost. The decision must be based on value judgments of various conflicting trade-offs. Examples include:

- Which brigade, X or Y, should receive the remaining artillery support?
- Which company should lead the attack?
- Which air squadron from which base should be sent to intercept approaching OPFOR aircraft?

It will be noted that the above definition of a Designation type decision is similar to the conventional terminology used to define the entire domain of decision making, i.e., the selection of an course of action from a set of alternatives. One of the distinguishing features of the ACADIA typology is that such a "selection" of a course of action is only one of a series of tactical decision tasks.

Because they largely involve analyses of pre-planned options and responses, this is the class of decision tasks best suited to a deterministic or algorithmic approach to decision aids. However, on the battlefield, many aspects of Designation type decision tasks involve consideration of subjective value judgments in the resolution of the underlying dilemma. For example, in the selection (designation) of the company to lead an attack, a battlefield commander will have to consider factors such as those shown in Table 4.

Table 4. Considerations in Resolving Designation Type Dilemmas

Decision Task: Select company to lead attack.

Factors:

- proximity to attack locale
- freshness
- resources (i.e., ammo, transport)
- experience of leadership and troops
- needs of subordinate tactical unit
- benefit to mission success
- amount of resources
- deliverability of resources
- need for reserves

Implementation Type Decision Tasks

Responses which are categorized as Implementation type decisions are those made in situations in which a particular course of action is known to be applicable but there remains the question of the proper moment to execute the action. The dilemma in this case is whether a given action should be performed now or at a later time. Waiting might improve the probability of success or bring about an opportunity for a new and better response to be made. However, waiting too long might prove disastrous, e.g., destruction of own tactical unit; escape of OPFOR, etc.

The dilemma facing the two protagonists in an Old West gun duel as they strode toward each other is a compelling example of an Implementation decision task. On a larger scale, the dilemma facing GEN Eisenhower as D-day approached is another example of an Implementation decision. On the one hand, the high likelihood of severe storms on the scheduled date made a successful channel crossing highly problematical. On the other hand, delaying the invasion might have had considerable negative consequences, e.g., loss of coordination, disruption of operations, reduced troop readiness, loss of momentum, and reduced surprise. Despite all of the analysis and advice available from hundreds of specialists, the ultimate decision task involved the resolution of the dilemma by Eisenhower himself; he had to decide whether or not to "implement" the plan at "H" hour on "D" day.

Some examples of the types of data and heuristics that would enter into the expert system knowledge base associated with the resolution of an Implementation type decision task are shown in Table 5.

Table 5. Considerations in Resolving Implementation Dilemmas

- Probability of success of own course of action
    - in a rapidly changing situation which is:
        - getting better
        - getting worse
- Probability OPFOR will continue its course of action
- Probability of aid from adjacent friendly units in attempting to resolve an unfavorable situation
- Ratio, in a direct confrontation, of the probability of success of own tactical unit versus
    - present value
    - future value
    - direction and relative rate of change of ratio
- Probability that the OPFOR maneuver is a feint
- Reversibility of action, e.g., start and then pull back (not possible in a gun duel)
- availablity and utility of subsequent options
- type of loss (e.g., resources, surprise, information)
- ability to recover from an initial unfavorable outcome

Some examples of advisory type of informational outputs that an expert system decision aid might provide in an Implementation type decision task include:

- advise if time is running out (based on normal operations as defined by SME's)
- advise if new or better information will probably be forthcoming
- advise of possible sources of information
- advise if aid from adjacent TU's or higher echelons may be available

Adaptation Type Decision Tasks

An Adaptation type decision can be characterized as a response of an unexpected threat of catastrophic proportion. That is, a situation whose significance is so apparent that it is not subject to the normal C2 process. Instead the C2 process is short circuited; transiting from the Information Gathering phase directly to the Decision phase.

Certain types of negative or positive events are expected to occur on the battlefield and contingency plans are usually made to respond to them. For example, both offensive and defensive operations usually maintain a substantial portion of forces in reserve to meet various possible contingencies. However, many situations arise for which it is not possible to devise appropriate contingency plans.

An Adaption type decision task requires decision maker to react quickly and appropriately to a change in the tactical situation that requires immediate action for the survival of the tactical unit or the success of its mission, e.g., depth bombs start exploding or an artillery barrage strikes in the vicinity of the tactical unit's location. Events requiring an Adaptation type decision response are usually negative (e.g., major OPFOR breakthrough on a flank) but may also be positive (e.g., total collapse of OPFOR resistance in a major sector).

The dilemma inherent in Adaptation type decisions is that on the one hand, the decision maker must do something or else face disaster. On the other hand, not enough information is available to make an informed, calculated decision. Reacting too quickly, with insufficient information, might place the tactical unit in a trap set by the OPFOR. However, over-analysis of the situation and of the possible response options might preclude enough time available for survival of the tactical unit.

An example of an Adaptation decision situation is the one facing the British high command in WWII upon the collapse of French resistance. The evacuation at Dunkirk is an example of a high level and successful Adaptation response.

The key features of an Adaptation type decision aid are:

1) ultra-simplified displays of graphics and option menus and 2) an information management and display architecture tailored to the echelon and combat function of the commander. At the lowest level, for example, it might be necessary to resort to an automated system for aiming and delivery of direct fires, with only an override option available to the commander. At a somewhat higher level, e.g., a tank platoon leader (TPL), an expert decision aid might provide a list of options, e.g., use smoke, perform maneuver X, call for artillery support. Color coding could be used to indicate the relative utility of each option. Appropriate second level graphics (e.g., a map display of a suggested escape route) and option menus would be made available via a single, simple input. At higher levels, where more time would be available, the systems would be more interactive and flexible but still oriented toward providing the user with a quick, workable solution rather than a thorough analysis of the situation.

Examples of the type of data and heuristics that would be included in the knowledge base of an Adaptation type decision aid are shown in Table 6.

Table 6. Considerations in Resolving an Adaptation Type Dilemma

- Escape route evaluation and recommendation
- Options available
    - counterattack
    - run
    - maneuver
- Type of loss trade-offs
    - materiel
    - personnel
    - mission capability
    - tactical capability
    - adjacent tactical units
- priority of actions
    - what to do first, second, third
- availability of more information
    - value
    - time needed to acquire
    - likelihood of getting information in time
- availability of assistance
    - adjacent TU
    - higher echelons
    - artillery, air, or other combat support
- amount of time available
    - to escape
    - to maneuver

SECTION III

EXPERT SYSTEM SAFEGUARDS AGAINST BEHAVIORAL LAPSES

Evaluation of decision performance is usually based on criteria derived from the "objective", observable results of the decision, e.g., occupation or defense of key terrain, enemy or friendly attrition rates, enemy vehicles destroyed, etc. Such objective criteria are obviously valid and necessary. However, in measuring effectiveness of an individual as a tactical decision maker, there are also important, significant criteria in the behavioral domain that should not be ignored. Such behavioral criteria are important in 1) training individuals to be effective tactical decision makers, and 2) in assessing evaluating the performance of commander's during tactical decision exercises, e.g., command post exercises (CPXs), war games, and simulations.

Decision makers often exhibit deficiences or lapses in the cognitive domain in the course of resolving the ACADIA dilemmas. Therefore, a valuable contribution to designing effective expert systems for tactical decision making would be to devise means to detect such lapses or deficiences in performance and assist the decision maker in overcoming them. Some examples of behavioral traits which could be monitored using expert technology during training and peacetime exercises of tactical decision making are discussed below.

Stereotypy

This term refers to the tendency to respond in a manner that is unnecessarily correlated with some other situational factor and thus renders the response predictable. For example, an individual may be given instruction about a number of evasive maneuvers that can be used to avoid a certain disadvantageous situation. If this individual selects one particular maneuver and uses it each time he is confronted with the unfavorable situation, his behavior becomes predictable to the OPFOR. This can greatly reduce his chance for mission success or even for survival. Stereotypy may manifest itself in any of the six decision tasks of the ACADIA typology. A good decision maker, therefore, is one who takes into account the pattern or frequency of his responses to certain recurring types of tactical situations.

The pattern of like responses need not be confined to an individual. It is also possible for stereotypy to manifest itself in similar behavior on the part of groups of individuals. For example, if all tank platoon leaders use the same evasive maneuver (that is one of a group of acceptable maneuvers) each time they are faced with a certain type of battlefield situation, an OPFOR who becomes aware of this fact would have a tremendous tactical advantage.

An expert "embedded tactician" that monitors the decision maker's responses for signs of stereotypy would be a valuable

decision aid. Expert system technology can be of assistance with regard to stereotypy in several ways, viz.;

1) Detecting patterns within individuals during training to help train out these patterns.
2) Detecting patterns among individuals during training to help train out these patterns.
3) Alerting a helicopter pilot during combat of similar responses he has made recently in similar situations
4) Alerting decision maker's to the existence of group patterns observed in training and recommending an alternative (for example, a tendency for division commanders to make a similar response to an OPFOR thrust or feint).

Perseveration

This term is used to denote a tendency to persist with a particular response (or interpretation) after it becomes more reasonable to make a different response. This factor is most likely to be manifest in situations requiring information type decision responses, i.e., Acceptance or Anticipation tasks, wherein a person persists with a given interpretation or hypothesis despite the fact that enough data have accumulated to make another hypothesis more tenable. An expert "embedded tactician" could evaluate the data and alert the decision maker to the possibility of "perseveration" in his analysis or interpretation of the emerging data.

Timeliness

This term refers to the relationship between the amount of time available to the tactical unit and the amount of time used by the decision maker. Inadequacies with regard to this trait are manifest in two ways, viz., the decision maker takes too long so that a potentially effective course of action can no longer occur, or the decision maker acts prematurely and thus runs an unnecessary risk of making a wrong response or otherwise disturbing the operation of the tactical unit.

Expert system technology could provide considerable aiding with regard to the "timeliness" of the decision maker. In the ACADIA approach the objective of such a system would not be to select arbitrarily the specific moment for the action but to provide the decision maker with information about the relationship between the effects of prematurity versus tardiness.

Completeness

This term refers to the degree to which a decision maker avails himself to all relevant information available in the tactical data base. A "good" decision maker is one who considers all of the factors that are relevant to the tactical situation and are permitted by time. If the amount of time available is

limited, a priority schema must be devised by the decision maker to govern his actions, e.g., the amount of time devoted to various categories of information or the level of detail at which information in any particular category is to be extracted. Expert systems can easily keep track of "relevant" information and adapt the priority level to the unfolding tactical situation.

Series Consistency

This term refers to the extent to which an individual makes consistent responses in a series of sequentially dependent or interrelated responses. An example of a lack of Series Consistency would be a plan that failed to provide proper air cover for the routes to be used to supply an advancing unit.

Series Consistency does not imply Stereotypy. Series Consistency refers to a relationship based on logic while Stereotypy refers to a relationship based on undesirable coincidence. Rule based expert system technology provides an effective approach to insuring Series Consistency of tactical decisions.

SECTION IV

SOME APPLICATIONS OF THE ACADIA TYPOLOGY

Operational Decision Support Systems

System Design and Operation

A tactical decision support system designed within the ACADIA framework would consist of an expert system that employs an executive expert that manages a tool box of expert subprograms (micro experts) and other computational routines. Both domain-specific and domain-independent heuristics, e.g., relevant ACADIA formats and processes, would be employed in the knowledge base.

The following is a general description of the sequence of actions and operations that would be involved in a C2 decision support system based on the ACADIA approach. At higher levels, the staff would perform the input functions ascribed to the commander.

a. The commander would recognize, or accept the judgment of his staff, that a particular type of dilemma exists. This acknowledgment in itself would provide a valuable informational input to the staff and provide them with a context for subsequent queries and information processing.

b. The expert system is informed of the existence of the particular type dilemma. Upon receiving this input, the system would automatically set up functions and products such as:

- a list of appropriate menus
- definitions of input needs
- protocols of data accumulation procedures
- automatically perform pre-arranged analyses
- display formats
- the appropriate data base structures

c. The system examines and organizes a data base derived by selectively extracting relevant data using pre-arranged procedures for accessing and manipulating data from the data bases of all staff elements (e.g., G1, G2) that might impact on the resolution of the dilemma.

d. The system requests information of the status of non-predictable data such as higher level guidance, battlefield contingencies, recent development, and situational assessments.

e. Commander inputs requested data.

f. System heuristics and meta-rules then supply pre-established default weights, e.g., priorities, worth, costs relevant to the resolution of the dilemma at hand.

g. The commander adjusts weights in accordance with his judgments regarding the tactical situation at hand. Note that this is both a help function and a prescription. By allowing the commander to discard or alter one or more of the criteria used by the expert system, it would be possible to delimit the search domains and processes involved in problem analysis.

h. The system produces and stores a hierarchically arranged display which highlights the major assumptions, considerations, problem areas, informational deficiences, and other important tactical variables.

i. The system analyzes the knowledge base, provides a summary display of its analyses and suggests actions to resolve the particular dilemma facing the commander along with a display of the pros and cons of the trade-offs available to the commander.

j. The system highlights the real or potential problems if the commander does not accept its advice or coaching. The commander is free to override or ignore the suggestions or cautions based on his military judgment and first hand knowledge of the battlefield environment and the needs and capabilities of his tactical unit. Whatever his decision, it is now made on a more informed basis.

<u>Technological Insertion</u>

The application of the ACADIA typology to the design of C2 decision aids does not necessarily require the availability of automation or the application of expert system technology. The basic notion could be used to improve tactical decision performance even in an entirely manual operation. ACADIA structures the knowledge base in terms of the specification and analysis of the trade-offs required of the user to solve the underlying dilemma. This approach leads to a more cognitively compatible framework within which the knowledge engineer can elicit information and the subject matter experts can articulate the data, rules, and heuristics that guide their decision making processes.

Much of this information could take the form of paper checklists that could support a staff during all of the phases of the C2 cycle even in the current, mostly manual, data processing environment such checklists would function largely as aids to insure that various critical factors were not overlooked and to make explicit the need for and implications of various trade-offs.

Command and control functions at all levels must be maintained in a state of constant readiness. For this reason, changes in the C2 process must be evolutionary to minimize perturbations caused by the introduction of new technologies. The ACADIA approach provides a framework for a gradual, multi-stage insertion of expert system technology into the C2 process as indicated in Table 7.

Table 7. Stage of Technological Insertion

1. A manual checklist that would serve as a mnemonic aid during operations and as a reference source during training.

2. A "dumb" automated checklist, i.e., a CRT display with scrolling, highlighting, indexing and other means for rapidly accessing lists of factors related to the resolution of a particular type of dilemma.

3. A "smart" automated checklist with limited user input capabilities, e.g., the user could insert weights and values for various parameters related to the resolution of the particular dilemma under consideration.

4. An interactive computerized checklist with capabilities to perform complex calculations and data manipulations to show the interplay of various dynamic processes or interactions (rates of movement, terrain analysis) that impact on the resolution of the tactical situation.

5. An "intelligent" automated system that emulates the actions (queries, recommendations, explanations) of a human expert advisor or coach.

Training

The ACADIA approach can add a new perspective to the procedures used to train tactical decision making skills in the classroom, in simulators, in CPXs and field exercises. By concentrating on a limited number of generic decision tasks (tactical dilemmas), the ACADIA approach enables a decision maker to reduce the problem to its essentials and to develop an individualized approach to addressing the issues involved in resolving the dilemma. This increases the likelihood that the student will learn to seek or examine all of the relevant factors in the decision situation and not become lost in the details related to just one or two anomalous factors.

The checklist of relevant generic features derived by the knowledge engineering process would in itself provide a very valuable mnemonic aid. Instructor manipulation of the weights and values assigned to the variables on the checklist could likewise provide an effective basis for classroom exercises.

The ACADIA approach provides a useful context within which an instructor can supply feedback during training. The student can be alerted to, and therefore avoid, cognitive lapses such as stereotypy or perseveration.

SUMMARY

Expert systems technology has shown great promise as a means for providing effective decision aiding in military command and control (Rouse, Geddes, & Hammer, 1990). But progress has been slow. A major impediment to the development of more usable expert consultation systems is the lack of a language for describing the cognitive components of human-computer interaction. The ACADIA typology provides some building blocks for a framework within which to develop such a language.

Each of the six ACADIA decision categories provides a broad context in which information gathering, analysis, and display parameters are defined by the users' needs rather than by the features of the specific application task. The ACADIA approach can be used in the design of generic expert consultation systems designed to assist or coach a decision maker in actual task performance. It is equally applicable to the design of training systems designed to impart knowledge and test the skill level attained or sustained by C2 personnel.

Because the ACADIA approach is suitable to manual as well as automated systems, continuity of C2 operations can be maintained during periods of technological insertion.

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